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Research Article

Fabrication of Simple and Ring-Type Piezo Actuators and Their Characterization

B. Sahoo and P. K. Panda

Materials Science Division, National Aerospace Laboratories, Council of Scientific and Industrial Research, Bangalore 560017, India

Correspondence should be addressed to P. K. Panda, pkpanda@nal.res.in

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A piezo multilayered stack of height 10 mm is fabricated using 80 μm thick PZT tapes prepared by tape-casting technique. About 120 layers of thin tapes are dried, screen-printed with Pt-electrode paste, stacked, laminated, and then isopressed to obtain a green multilayered stack. Cofiring of the stack is carried out at 1250°C for 1 h with very slow heating rate (15° per 1 h). The sintered stack is poled at 2 kV per mm in hot (120°C) silicone oil bath for 45 minutes, and free displacement and block force were characterized. The actuator generates free displacement of 10 μm (0.1% strain) and block force of 1427 N at 175 V. In a similar way, a ring-shaped multilayered PZT stack was fabricated; the displacement was measured to be 8 μm. The ring-type actuator is mainly used for fluid flow control in space vehicles.

1. Introduction

Piezo actuators/sensors are mainly used for smart applications because of their (i) fast response time, (ii) high frequency response, (iii) precession control, (iv) capablity of generating high block force, and so forth [1]. The sensors and actuators with appropriate control unit together form a smart system. Piezo sensors and actuators are used for various applications such as vibration control of aerospace structures, development of smart aeroplane wings, propellant flow control in space vehicles, and fuel flow control in automobile engines. Lead zirconate titanate (PZT) is a well-known piezo material that produces electric charges on application of mechanical stress (as sensor) or undergoes dimensional change when subjected to an electric field (as actuator) [2–6]. For these properties PZT is frequently used for fabrication of multilayered actuators. Ring-type actuator is a special type of actuators exclusively used for flow control purpose. Weight/size reduction of a space instrument or subsystem of a space craft is necessary to save enormous launching cost as well as to increase the mission duration. The reduction in thrust levels for miniaturized spacecraft requires very fine propellant flow rates. Solenoid valves used for flow control are very heavy. Piezo-material-based microactuators could be best suitable for these applications due to their precision flow control [7] effected by the gradual application of voltage and also due to their low weight.

Therefore, in this study, an effort has been made to fabricate PZT multilayered stack and a ring-type actuator by tape casting technique and block force and displacement were characterized.

2. Experimental Procedure

2.1. Fabrication of Simple Multilayered (ML) Stack. PZT stacks were fabricated by tape casting method using in-house prepared PZT powders [8]. A well-dispersed PZT slurry was prepared using required amount of PZT powder, organic solvents (methyl ethyl ketone and ethanol), dispersant (Triton), binder, plasticizers, and so forth, by ball milling for 72 hr. The slurry was then filtered and cast on a silicon-coated Mylar sheet using a laboratory tape caster. The thickness of the green tapes is varied between 20 μm and 200 μm by changing the parameters such as the clearance of doctor blade, the casting speed, the viscosity of the slurry. The process flow sheet for fabrication of ML stack by tape casting technique is presented in Figure 1.

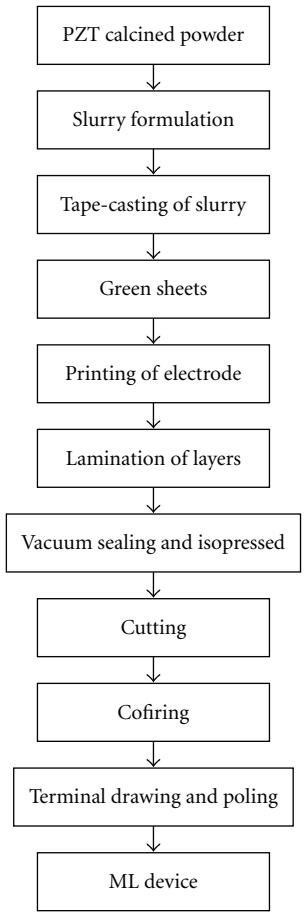

Figure 1: Process flow sheet for fabrication of ML stack by tape casting technique.

The green tapes of thickness 80 μm were dried, cut into required dimensions, screen-printed with platinum electrode paste, and dried. The individual layers are then stacked and laminated one above the other using uniaxial stacking machine. Following the above procedure, a ML stack of height 12 mm (green stage) is fabricated. The stack is then iso-pressed at 30 MPa for 5 min with preheating at 60°C for 5 min. Binder burnout of the stacks is carried out at 520°C for 2 hours with very slow heating rate (15° per 1 h). The cofiring of the stack is done at 1250°C for 1 h. The stack is leveled to have parallel surface, finished and electrode, and two terminals are drawn by soldering the wires. The photograph of fabricated simple ML stacks is shown in Figure 2. The stack is then poled at 2 kV/mm in hot (120°C) silicone oil bath for 45 minutes, and displacement and block force were characterized.

2.2. Fabrication of the Ring Actuator

2.2.1. Working Principle. The design of the actuator is mainly used for the flow control of fluid. The ring portion of the actuator in inverted position is glued to a substrate. On application of dc voltage, the active ring stack expands in upward direction and the middle inactive rod attached to the cap remains as such which produces a gap in between the substrate and the middle rod and facilitates the flow of fluid. A schematic diagram for flow control using this actuator is presented in Figure 3.

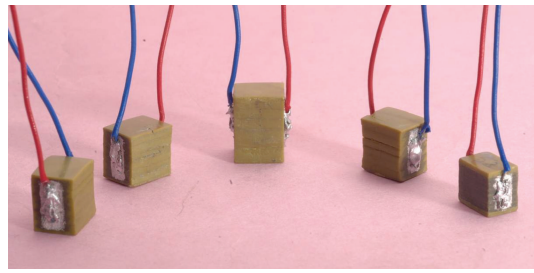

Figure 2: Photograph of in house fabricated simple ML stacks.

2.2.2. Fabrication. The ring-type actuator consists of three parts: (i) an active PZT ring stack prepared by 70 layers of annular-shaped (ID = 12 mm, OD = 18 mm) PZT tapes stacked using platinum as internal electrode, (ii) a central cylindrical PZT rod of 8.7 mm diameter fabricated using 80 piezo layers, and (iii) the inactive circular base consisting of 10 piezo layers. The final ring actuator was fabricated by attaching the central rod and active ring stack to the circular PZT base such that a gap is maintained to facilitate the displacement of the active ring actuator. The photograph of the fabricated actuator is presented in Figure 4. The final dimensions of the actuator are (i) height: 12 mm, (ii) internal rod diameter: 8 mm, and (iii) ring diameter: 15.5 mm (outer) and 9.5 mm (internal).The active region of the stack was electrode and poled at 2 kV/mm and, the displacement was measured.

3. Results and Discussions

3.1. Measurement of Displacement and Block Force. The displacement of fabricated simple ML stack and the ring actuator was measured without application of mechanical load. The actuator is placed on a plane rigid support on top of which the tip of the strain gauge is placed with an initial reading set to zero. A test set-up measurement for displacement of the PZT stack actuators is presented in Figure 5.

The terminals of the actuator are connected to appropriate terminals of a dc source, and the voltage is gradually increased. It is observed that the displacement increases with the increase in voltage and a maximum displacement of 10 μm and 8 μm is measured for simple ML stack and ring actuator, respectively. The typical plot of the displacement versus voltage is presented in Figures 6 and 7, respectively.

The simple ML stack is characterized for block force using a block force measuring unit (Figure 8). The actuator is placed on top of a force sensor (load cell) inside the sample holder, and its positive and negative terminals are properly connected to the respective terminals of the voltage source. For measurement of block force, a constant prestress is applied from top of the actuator through 3-4 springs of

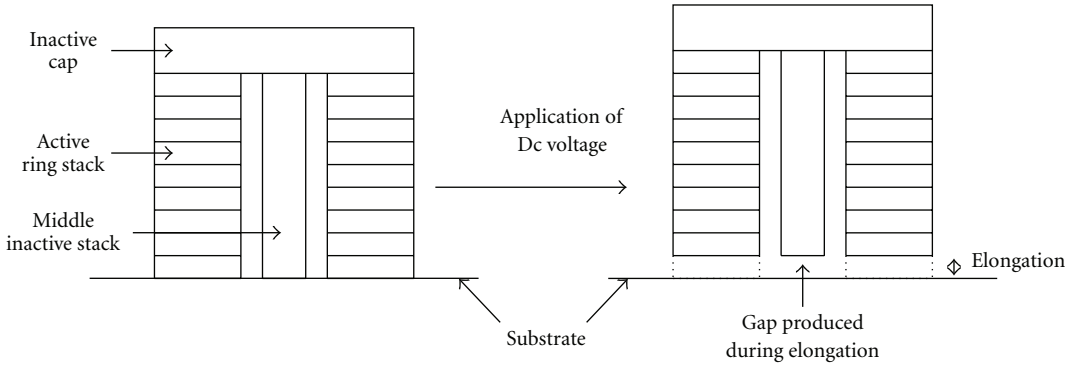

Figure 3: Working principle of a ring actuator.

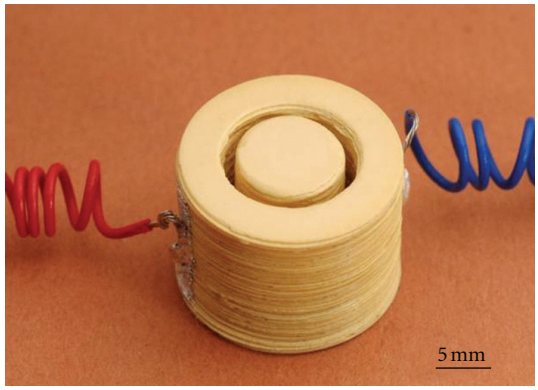

Figure 4: Photograph of fabricated ring actuator.

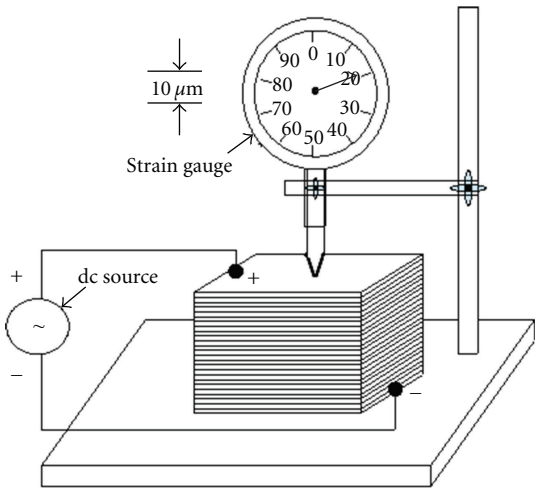

Figure 5: A test set up measurement for displacement of the ML stacks.

different stiffness. The actuator observes higher force with the spring having higher stiffness. The values of displacement and force generated by the actuator for all the springs are plotted by block force measurement software. It is observed that a maximum block force of 1427 N is obtained at 175 V.

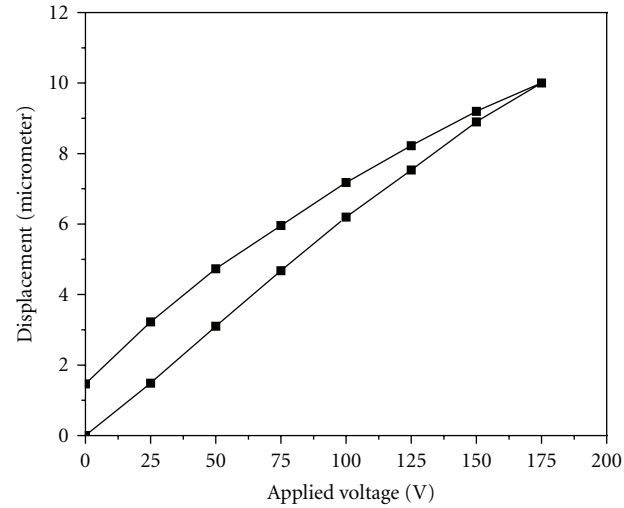

Figure 6: Displacement versus voltage graph of simple ML stack.

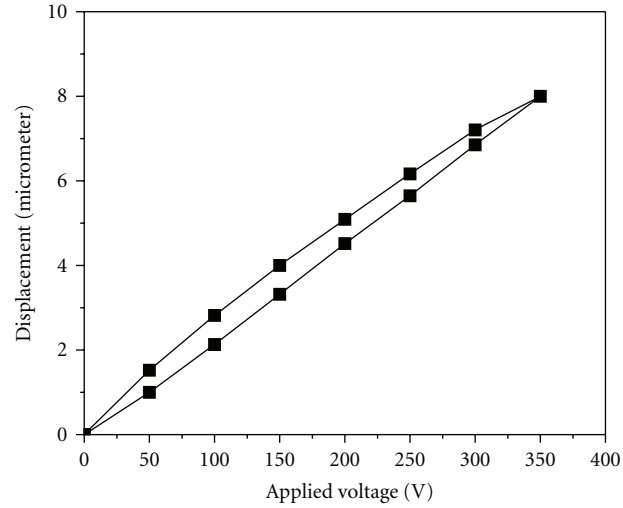

Figure 7: Typical plot of the displacement versus voltage of ring actuator.

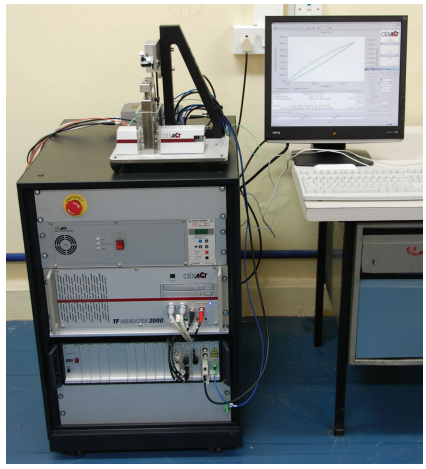

Figure 8: Photograph of the block force measurement unit.

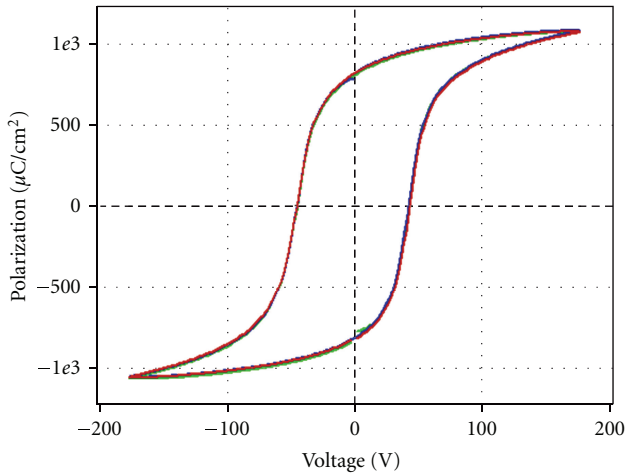

Figure 9: Typical hysteresis curve of fabricated ML stack.

The hysteresis of the PZT stack was also measured using the same equipment. The hysteresis curve generated for the PZT stack is shown in Figure 9. It is observed that the remnant polarization (P_r) and coercive field (E_c) are 804 μC/cm^2 and 41 V, respectively.

4. Conclusions

A piezo multilayered stack of height 10 mm is fabricated using 80 μm thick PZT tapes prepared by tape casting technique. It generates free displacement of 10 μm (0.1% strain) and block force of 1427 N at 175 V. The remnant polarization (P_r) and coercive field (E_c) of the stack are found to be 804 μC/cm^2 and 41 V, respectively. A special type of ring actuator was fabricated by tape casting technique using in-house-prepared PZT powder. The displacement of the actuator was measured to be 8 μm at 350 V. It was observed that the displacement is almost linear to the applied voltage; therefore, the precision control of the fluid flow is expected.

Acknowledgments

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